HOVEY INDUSTRIES LTD.

2378 Holly Lane, Ottawa, Ontario, Canada K1V 7P1 613-731-1200 Telex 053-4922
P.O. Box 116, Port Authority Bldg., Ogdensburg, New York, U.S.A. 13669 315-393-0670

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POWER MANAGEMENT ON RAIL PASSENGER CARS

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Prepared By
B. Bramwell
P. Manashe
Hovey Industries Ltd.
2378 Holly Lane
Ottawa, Ontario
K1V 7P1

Hovey File 2007

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PROJECT TEAM

The Project Team for Hovey Industries Ltd. was composed of:

B. Bramwell, P. Eng.
P. Manashe, P. Eng.
W. Gamblin, P. Eng.
J. Hurst
and others

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17. Abstract

This report presents the results of a study of electrical power consumption on intercity rail passenger cars. The objective was to identify system modifications and operating procedures that can reduce the peak demand on the electrical power generating equipment of a passenger train. A literature search and discussions with VIA Rail and Amtrak revealed that little emphasis had been placed on this issue in the past, even though peak electrical load can determine the number of locomotives needed to haul a given consist, and therefore significant economic and fuel efficiency benefits could result from improved power management.

A detailed electrical analysis of VIA's LRC train was performed, based on test measurements of current consumption of the various subsystems. The report discusses the following approaches to reducing peak power demand: improved efficiency in the electrical system, reduced power surges, loads staggered in time, and reduced electrical demand. For future trains a distributed automated power control system is proposed.

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17. Resumé

Ce rapport rend compte de l'étude faite sur la consommation d'énergie électrique à bord des trains voyageurs, et dont l'objectif était de trouver des moyens et des méthodes susceptibles de réduire les crêtes de charge imposées au matériel embarqué de production d'électricité. Une recherche documentaire et des rencontres avec VIA Rail et Amtrak ont montré que, jusqu'ici, cette question n'avait suscité que peu ou pas d'intérêt, même s'il est admis que le nombre de locomotives nécessaires à la traction d'un convoi donné soit lié à l'importance des pointes de demande d'électricité. D'où l'intérêt économique évident d'une bonne gestion de l'énergie électrique à bord.

Une analyse détaillée de la consommation d'énergie électrique à bord des trains LRC de VIA Rail a été faite, fondée sur des données chiffrées concernant la consommation des divers sous-systèmes. Le rapport décrit les méthodes suivantes susceptibles de réduire les crêtes de charge: meilleur rendement du système électrique dans son ensemble, réduction des appels de puissance transitoires, décalage des charges dans le temps et réduction de la demande. Le rapport propose l'étude d'un système automatique de gestion de l'énergie électrique par une distribution contrôlée de cette énergie.

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1.0 INTRODUCTION

The peak electrical power requirement of railway passenger cars has a significant effect on overall operating costs and fuel consumption because, in addition to the costs of generating the power, additional locomotives may be required to provide an adequate power supply. VIA Rail Canada Inc. has identified this area as one in which important savings could be made through changes in operating procedures, modifications to existing equipment and guidelines for future car design. This project involved the study of the electrical systems of VIA passenger trains and international design practice to identify and quantify the potential savings which could result from a reduction in peak power demands; followed by an analysis of present passenger car power requirements and an investigation of means of reducing peak requirements. Based on this data, recommendations on operating procedures, equipment modifications, design guidelines and further studies and testing have been made.

2.0 LITERATURE SEARCH

A comprehensive literature search was conducted through the following sources:

1. VIA Rail Library
2. National Research Council Canadian Institute for Scientific and Technical Information Library
3. Carleton University Library

A list of the most relevant references can be found in Appendix A.

This search turned out to be very disappointing as there is little or no information that we could locate on power management on trains or even on power conservation with individual systems.

Contact was also made with representatives of VIA Rail and Amtrak in the United States of America but there appears to have been little or no work done in the past to minimize electrical power consumption in rail passenger vehicles.

3.0 VIA LRC ELECTRICAL ANALYSIS

The following four tables document the electrical resistance and current demand (peak and steady state) for most of the electrical circuits in the LRC coach.

Table 1 shows the cold resistance of the heater elements in the LRC 2 coach. It is felt that due to the lower resistance of the heater elements, large inrush currents will occur upon turn on of these heaters.

This effect will contribute to significantly increase the peak load on the system. Furthermore, the fact that the turn on sequence is random, there is no way of predicting when these power surges will occur. Our suggestion is to use electronic controls that will provide for slow start of the heaters in order to eliminate the initial surges. This can be very easily accomplished if more modern microprocessor based systems would be used.

In addition to limiting the inrush currents it is recommended that the microprocessor controller would also implement a finer degree of regulation from the present 3 step system of control.

The tables show that the main electrical loads come from the heating and air conditioning system. It follows then that the greatest potential for electrical energy savings come from these two areas.

TABLE 1

LRC-2 COACH

COLD RESISTANCE OF HEATERS

ITEM	DESCRIPTION	COLD RESISTANCE IN OHMS @22°C, PER PHASE OF A THREE PHASE SYSTEM
1	VESTIBULE	98.8
2	OVERHEAD HEATERS FIRST STAGE	50.2
3	OVERHEAD HEATERS SECOND STAGE	64.1
4	FLOOR HEATERS FIRST STAGE	58.2
5	FLOOR HEATER SECOND STAGE	49.8
6	BANKING HEATERS	76.2
		COLD RESISTANCE IN OHMS @22°C
7	HEAT TRACING AFB-1	9.5
8	HEAT TRACING AFB-2	8.9
9	HEAT TRACING AFB-3	14.7
10	HEAT TRACING AFB-4	10.6
11	HEAT TRACING AFB-5	21.3
12	HEAT TRACING AFB-6	24.9
13	HOT WATER TANK	11.2
14	CONVECTION OVEN	11.2

NOTE: 1. Each coach contains 1 piece of items #1 and 6 and 2 pieces of each of items 2, 3, 4, 5, 13 and 14.

2. The above resistance values are not the resistance values during steady state operation.

TABLE 2

LRC-2 COACH

HEATER CURRENT CONSUMPTION

ALL MEASUREMENTS WERE CONDUCTED @22°C AMBIENT TEMPERATURE

ITEM	DESCRIPTION	CURRENT CONSUMPTION EACH HEATER	CURRENT CONSUMPTION TOTAL
1	VESTIBULE	5.5A	5.5A @ 480V AC
2	OVERHEAD HEATERS FIRST STAGE	10A	20A @ 480V AC
3	OVERHEAD HEATERS SECOND STAGE	8A	16A @ 480V AC
4	FLOOR HEATERS FIRST STAGE	20A	40A @ 480V AC
5	FLOOR HEATERS SECOND STAGE	20A	40A @ 480V AC
6	BANKING HEATER	7A	7A @ 480V AC
7	HEAT TRACING AFB-1	3A	3A @ 120V AC
8	HEAT TRACING AFB-2	3.8A	3.8A @ 120V AC
9	HEAT TRACING AFB-3	1.4A	1.4A @ 120V AC
10	HEAT TRACING AFB-4	2.3A	2.3A @ 120V AC
11	HEAT TRACING AFB-5	1.9A	1.9A @ 120V AC
12	HEAT TRACING AFB-6	1.6A	1.6A @ 120V AC
13	HOT WATER TANK	2.8A	5.6A @ 208V AC
14	CONVECTION OVEN (2 PIECES)	3.A 1.7A	4.7A @ 208V AC

NOTE: 1. Measurements were performed on one LRC -2 Coach. These measurements may not be typical.

2. The heat tracing loads do not represent the maximu load as the heat tracing cables are self limiting.

TABLE 3

LRC-2 COACH

CURRENT CONSUMPTION OF MISC LOADS

ALL MEASUREMENTS WERE CONDUCTED @22°C AMBIENT TEMPERATURE

		CURRENT CONSUMPTION	
ITEM	DESCRIPTION	EACH LOAD	TOTAL
1	COMPRESSOR MOTOR (AIR CONDITIONING)	8A AVERAGE 135A SURGE	16A @ 480 V POWER FACTOR 0.86
2	EVAPORATOR FANS (AIR CONDITIONING)	2.25A	4.5A @ 480V POWER FACTOR 0.86
3	BANKING MOTOR	NOTE ABLE TO MEASURE DUE TO DISCONNECTED HOSES	
4	LIGHTING	6A, 7A	2.5A PER PHASE @480V
5	POWER SUPPLY FOR EMERGENCY LIGHTING AND CHARGER	1.7A	1.7A @ 480V IN 10A @ 70V OUT

NOTE: 1. The conditions during testing for the air conditioner were very moderate. Under severe conditions the air conditioner could draw up to 27 amps or over 3 times the value recorded.

TABLE 4

SUMMARY

	MEASURED VOLTAGE AND CURRENT	POWER CONSUMPTION
HEATERS	128.5A @ 480V AC-3 Phase	185 Kw
HEAT TRACING	14 Amps @ 120V AC	1,680 Watts
HOT WATER	5.6A @ 208V AC	1,165 Watts
*AIR CONDITIONER	(a) 20.5A @ 480V - 3 Phase (b) 39.5A @ 480V - 3 Phase	29 KVA 56 KVA
CONVECTION OVEN	4.7A @ 208V AC	978 Watts
BANKING MOTOR	UNABLE TO MEASURE	
LIGHTING	2.5A @ 480V	3.6 Kw
EMERGENCY LIGHTING & CHARGER	1.7A @ 480V	800 W

*Two values are listed

A - As Tested

B - Theoretical maximum current consumption

4.0 REDUCTION OF PEAK ELECTRICAL LOADS IN TRAINS

4.1 General

The reduction of the peak electrical load in trains can be achieved in three ways:

1. The reduction of the average power consumption through improved efficiency of the electrical system.

2. The reduction of power surges, or the staggering of electrical loads in order to distribute the peak loads over a longer period of time.

3. Reduction of electrical demand (i.e. improved insulation to reduce heater size).

4. Several suggestions for achieving the above are discussed. Many of these suggestions are not practical or cost effective at this time with existing technology. They have been mentioned however so that if the technology becomes more cost effective in the future they might be considered.

4.2 Improving Efficiency

Improved efficiency of the electrical system can be achieved by the following means:

1. Use of proportional controls for heaters.

2. Use of heat pumps for heating and cooling in conjunction with electrical heaters for peak loads.

3. Use of the highest possible voltage for distribution of electrical power to reduce losses in cables. The voltage magnitude will be influenced by safety considerations.

4. Use of high voltage switching regulators instead of 60V regulators. This could improve the conversion efficiency from approximately 80% to 98%.

5. Implement charging of batteries during braking periods.

6. Install ducts for transfer of hot air from over-heated compartments to colder compartments.

4.2.1 Use of Proportional Controls for Heaters

Present trains use a three-step heater control. Consequently, in many situations the generated heat is too high or too low. The use of an eight bit (256 step) microcomputer controlled proportional controller would adjust the heater output much more closely to the level required by changing the on/off duty cycle of the heaters. Furthermore, the above microcomputers could be arranged in a network that would enable the microcomputers to communicate with each other. A master microcomputer, controlling the whole network could ensure that only a limited number of heaters are on at a given time, therefore further reducing the peak load and losses in the electrical wiring.

4.2.2 Use of Heat Pumps

The use of heat pumps could reduce the electrical energy consumption by 25 - 30 per cent on the average. Heat pumps only transport heat rather than generating it. As a result, less electrical energy is required for the same heating or cooling cycle compared to heaters or air conditioners.

In the summer period, the heat pump would transport the heat from the passenger compartments to the outside. There the heat would dissipate into the environment.

In the winter period, the heat would be collected on the outside of the train car by a radiator element. The collected heat would then be transported by the heat pump inside the passenger compartments.

The peak heating requirements could be handled by electrical resistance heaters.

4.2.3 Use of the Highest Possible Voltage for Distribution of Electrical Power

The electrical power delivered to the heaters or any other electrical appliance is the product of the voltage and current. The losses in the electrical wires are dependent on the resistance of the wire (i.e., its length and cross section) and the current that passes through them. If the distribution voltage could be raised, the following advantages could be gained:

1. Lower power losses in the wiring
2. Smaller wires could be used
3. Reduced weight of the wiring

4.2.4 Use of High Voltage Switching Regulators

Switching regulators are used in many mobile applications because of their high efficiency of power conversion. Ideally, it is desired to bring the conversion efficiency as close to one hundred per cent as possible. Usually, the conversion efficiency is degraded by a combination of four factors:

1. Switching losses
2. Losses across the output diode rectifiers
3. Losses due to leakage current and saturation voltage across the switching transistors
4. Losses in the magnetic components

Points (1) and (4) can be improved by the choice of good magnetic materials and increased frequency of operation. Present switching regulators operate in the frequency range of 25,000 to 60,000 Hz.

Increasing the operating frequency to a range of 250,000 to 1,000,000 Hz would decrease losses as well as decreasing volume and weight.

Losses in the switching components (transistors, diodes) can be decreased to a certain extent by the choice of suitable components.

A better strategy would be to increase the input voltage to the regulators so that the voltage lost across the switching components would represent a smaller percentage of the overall voltages switched. For example, to obtain a 600W output at 65V input voltage to the switching regulator, an average current of 10A has to flow through the regulator. As the peak currents are usually four times the average current, the switching transistors have to handle approximately a 40A peak current. The usual 2V voltage drop across the switching components represents a relatively large portion of the input voltage.

If the same regulator would use an input voltage of 600V, the required currents would be only 1A average and 4A peak. At that current, the voltage drops across the switching components would be much smaller, and the voltage drops would be a small fraction of the input voltage. Hence, a significant increase in efficiency could be realized.

The choice of the above voltages will be influenced by safety considerations.

4.2.5 Implement Charging of Batteries during Braking Periods

During the braking period, the train mechanical energy could be converted into electrical energy by using an alternator with rectifiers. This energy could be captured in batteries and reused at a later date. We are not aware however, of any cost effective system of this type available at this time.

4.2.6 Ducts for Transfer of Hot Air

Ducts could be installed between passenger compartments. Each of these ducts would have remotely microprocessor controlled valves and fans.

The valves could establish a path from an overheated passenger compartment (with many passengers) to a colder compartment with few passengers. The fans would then equalize temperatures in the compartments by transferring some hot air from one compartment to the other. The equalization will occur without the generation of additional heat. We doubt at present that this could be done cost effectively.

4.3 Reduction of Power Surges

The reduction of power surges could be achieved through the following:

1. Incorporate slow start circuits for all electrical motors and closed loop microprocessor based speed controls for compressors in the air conditioning units.

2. All heaters could have proportional microprocessor based controls which would turn the heaters on gradually without the usual initial surge. This power surge is caused by the fact that the heater wire has a much lower resistance in its intial cold state.

3. Staggering of the peak loads that occur during the startup phase of the equipment and accessories. This could be accomplished by a network of microprocessors which communicate with each other.

4.3.1 Slow Start Circuits

The slow start circuits would eliminate high peak surges by gradually starting electrical motors. Additional improvements could be obtained by controlling the compressor speeds so that a gradual performance curve is obtained instead of a three step control. (Figure 1).

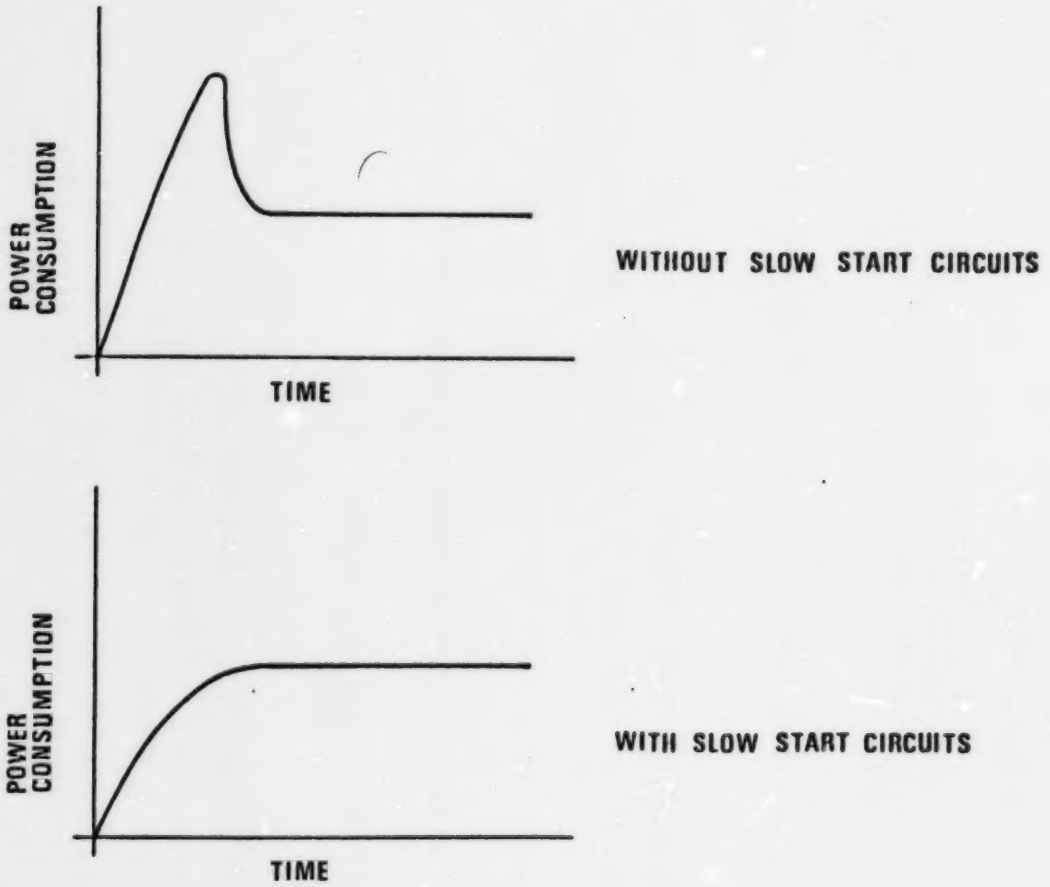


FIG. 1 EL. MOTOR POWER CONSUMPTION

4.3.2 Proportional Microprocessor Based Heater Control

Heater elements have a low resistance when cold and a higher resistance at full temperature. This tends to create high peak electrical demand upon turn-on. A proportional controller would supply less current or voltage at the beginning therefore eliminating peak current surges.

4.3.3 Staggering the Peak Loads

This technique would not eliminate the surges, but distribute them over a short period of time. This would greatly decrease the peak electrical load required when many appliances start up at the same time. (Figure 2)

The above could be synchronized by using a network of microprocessors which communicate with each other through a simple wire loop.

4.4 Reduction of Electrical Demand

The reduction of electrical demand can be accomplished by the following:

1. Improved insulation in the walls, ceiling and floor of the train.

2. Insulated shades that could be pulled over windows at night.

3. Waste heat from the locomotive could be transmitted to some of the cars.

5.0 FUTURE TRAIN ELECTRICAL SYSTEM CONTROL

The following is a proposed solution for reducing the peak power demand upon a diesel locomotive generator.

By cutting the peak electrical demand of each car we could increase the length of the train without exceeding current peak diesel generator capacity. We propose to cut the power by implementing a distributed automated control system. This system would control devices more efficiently, thereby reducing peak power consumption. Peak power consumption will also be reduced by having a central computer stagger the filling of power requests in order to average out the peak power demands of the train.

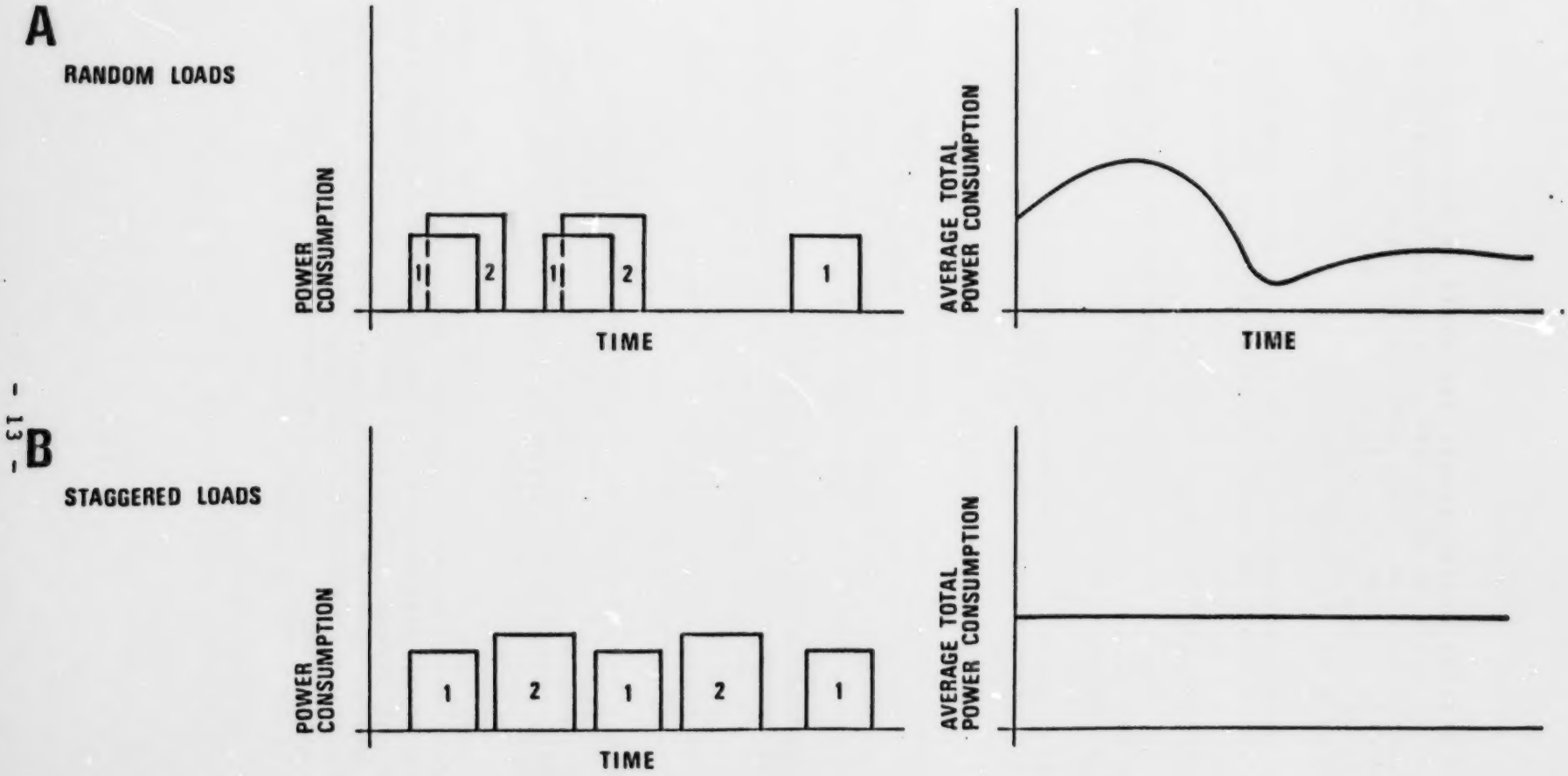


FIG. 2 BENEFITS FROM STAGGERED LOADS

A central master controller would be placed in the locomotive. It would be connected to a local controller in each car by a nine wire cable. This cable will carry status information from the car controller to the master computer. As well it will carry the control information from the master computer to each of the cars. (Figure 3)

A diesel locomotive train is made up of a diesel locomotive and a train of cars. Electrical power for the train is generated by a diesel generator in the locomotive and traction driven electrical generators on each car.

The number of cars in the train is limited by the peak generating capacity of the diesel generator. This must be large enough to supply large surges in demand due to:

1. Loads being turned on randomly
2. Inefficient power control in car electrical devices
3. Normal usage profile during a train journey

Loads being turned on randomly create a peak in power demand when a number of loads all come on during a short period of time. For example, air conditioner compressor, fans, vestibule heater, coming on coincidentally at the same time.

Randomness arises from two sources. Several devices are under manual control. Therefore, it is unpredictable when they will be turned on. Each heater is controlled by an independent thermostat. Presently the locomotive must have a great deal of extra capacity in order to handle the possibility that all devices come on at once.

The power control on car devices is built for simplicity rather than energy efficiency. Consideration is not given for slow start-up of coil devices such as motors and heaters. This inefficiency leads to large power demand spikes when a coiled device is started.

Large surges in demand are also caused by the normal usage pattern during a train journey. When the locomotive is accelerating, more diesel power is needed for overcoming inertia and rolling resistance. This cuts the power available for car electrical needs. During the evening a large surge is caused when all the train's passenger lighting is turned on. During meal times more power is needed for convection and microwave ovens as well as water heating.

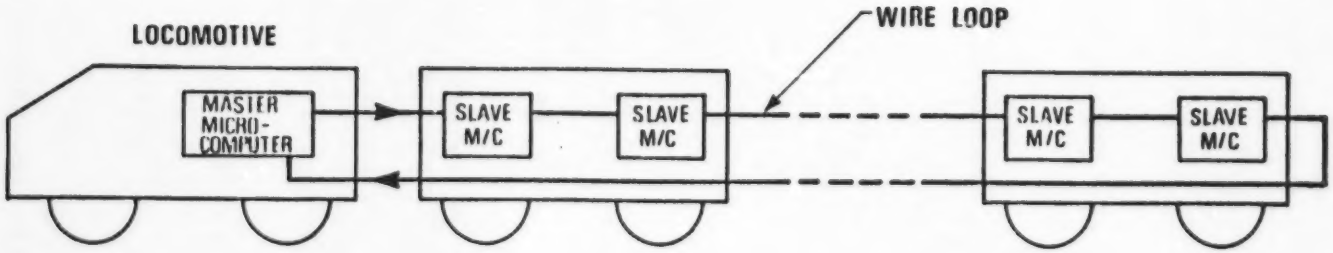


FIG. 3 MICROCOMPUTERS COMUNICATE WITH EACH OTHER THROUGH A WIRE LOOP

5.1 Advantages of Automating Power Control

The lion's share of car power demand is for heating. Each LRC car has a 32 kW overhead heater, a 32 kW floor heater, a 5 kW vestibule heater, and a 6 kW banking heater. Currently each unit is controlled independently. Each unit comes on randomly. Control over the heater is very inefficient. Thermostats have only three settings, high, medium or low. This lack of precision means that often more power is being supplied than required for car heating or passenger comfort.

Three modes of power control are being proposed in this report:

1. Duty Cycle
2. Voltage ramps on start-up of all car devices
3. Car demand limiting
4. Time of day/season control

All three modes require dropping electrical loads which may be shed without affecting passenger comfort or safety. All car loads are sheddable except for emergency battery charging, banking motor power and banking motor heating.

Duty cycle control of the heaters would lead to considerable reduction in the peak power demand. One hour previous to the start of a journey, the power control unit would turn on. Power to the heaters would be staggered until each car is brought up to temperature. During travel each car's heaters would only be allowed to be turned on, say, for a fifteen minute period every hour. Thermostats in the car would determine the heat output from the heater.

Peak power demand would be further reduced by having each heater turn on slowly. Heater coil resistance is initially very low. When a heater is turned on a large current spike flows through the heater causing a peak in the electrical power demand. In the new system we would have the applied voltage ramp slowly up to the desired level, thereby reducing the peak power demanded.

Time of day/season control involves reducing the comfort temperature in the car during the night and in different seasons. This will reduce the peak power demand during the evening when more power is needed for lights.

5.2 Communication

Communication between the locomotive and cars would be

over a 28 node multi-drop segments connected by repeaters. A maximum of 250 nodes are allowed in the system. The master communication controller is in the locomotive. Each car is a slave along the multi-drop line. Only the master can initiate sessions. Communication is in a hierarchical manner which reduces the protocol complexity over a peer relationship where any device can initiate a session. (Figure 4)

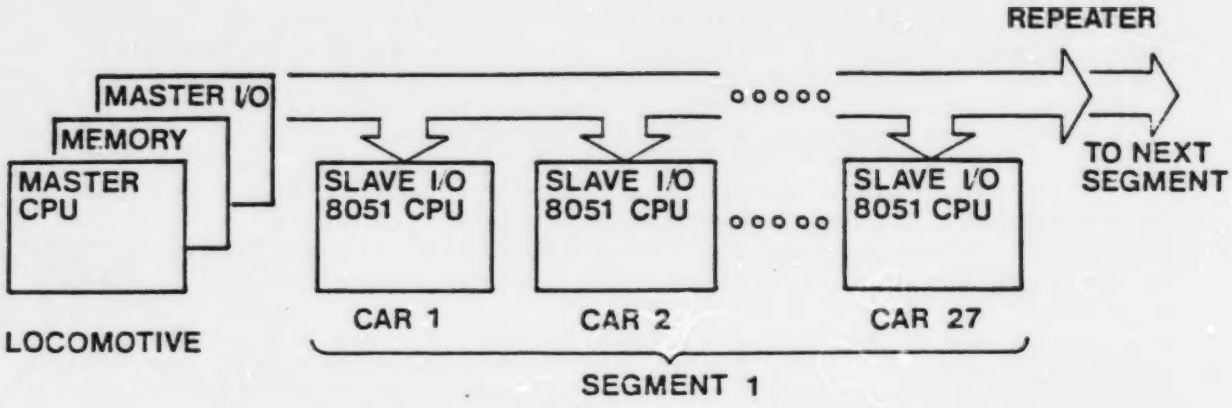
The master controls all message traffic and initiates all messages. Slaves answer each message with either an immediate acknowledgement to confirm correct recognition, or with a response message associated with a previously received command.

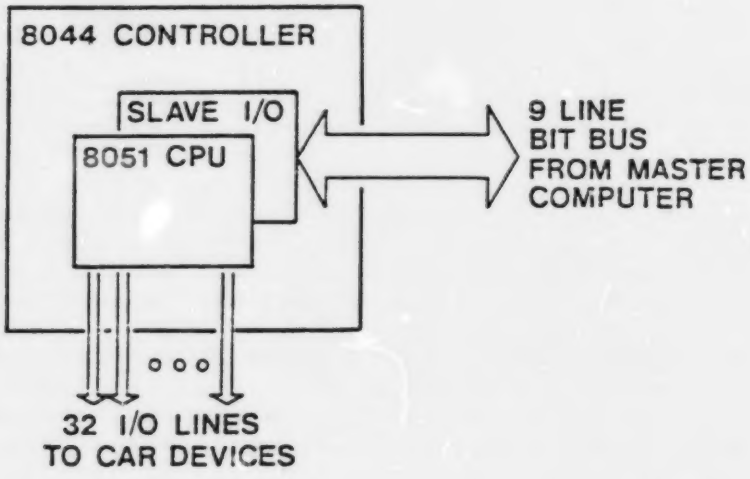
All communication would be over a nine wire cable called the Bitbus. The Bitbus interconnect is based on the SDLC (IBM's synchronous data link control) standard built into the 8044. SDLC is well suited for reliable transmission of short, control-oriented messages. This is because it has low overhead and a built in data security and acknowledgement protocol.

The 8044 Bitbus micro-controller supports a large subset of the standard SDLC protocol. All slaves operate in auto-mode. In this mode all 9DLC functions are managed automatically. The Bitbus would operate in self-clocked mode in order to allow longer distance operation. The Bitbus supports a segment up to 300 meters in length at 375 kbits/sec. Each segment supports up to 28 nodes. By connecting segments with repeaters, this mode supports up to 250 nodes over several thousand meters. The self clocked mode uses two differential signal pairs: one for data (DATA, DATA*) and one for transceiver control (RTS, RTS*). This encoding method combines clock and data onto the same signal pair. The transceiver control signal pair is used to control transceivers within the repeaters.

All signals on the Bitbus interconnect are differential pairs. The naming convention for these pairs identifies the two signals as NAME AND NAME*. An active signal is present when the NAME signal line is at a higher potential than the NAME* signal line. An inactive signal is present when the NAME signal line is at a lower electrical potential than the NAME* line signal line. Bitbus electrical specifications are based on the RS-485 electrical standard.

Each car would contain an 8044 single chip micro-controller. This chip contains two units: an 8051-like processor core and an SDLC serial interface unit. The onboard processor contains 4 Kbytes of read-only memory, 192 bytes of read/write memory, 31 I/O lines, two 16 bit counters, priority interrupts, 12 MHz real time clock and can access up to 64K of external program memory.





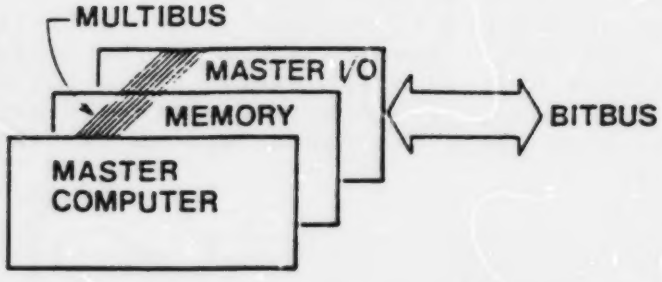


FIGURE 4 - TRAIN POWER CONTROL SYSTEM

5.3 Main Computer

A main computer in the diesel locomotive would handle processing of messages to and from cars. When polled by the master, cars would ask this computer for permission to turn on a device. Power demand requests would be placed in a priority queue.

Duty cycle tables would also be maintained. By automating the heating of individual cars we would remove the randomness from the turning on of devices. Tables would be used to schedule which car should be heated next. By staggering the heating of individual cars the demand is averaged out, thus removing the peaks from the demand curves.

When a car turns off a device it passes the message to the main computer (on its poll turn) which then updates the current power demand record. The main computer would then grant the freed up power to the highest priority devices waiting on the queue.

The main computer would be connected to the 8044 slave controller in each car by an 8044 made through the bitbus.

5.4 Car Controllers

Each car controller is connected to the communication bitbus by an Intel 8044 chip. The car controller is connected and a slave to the bus. It cannot initiate a communication session, it can only respond to sessions initiated by the main computer through the master controller.

When polled the car controller passes messages to the main computer. The messages would be car temperature, humidity, ambient lighting, requests to turn on devices and information that a device is being turned off.

The car controller would be connected to the fans, overhead heater, baseboard heater, vestibule heater, banking heater, lights, convection oven and all other car devices. It would be connected using the 32 I/O lines of the 8044. The slave would control the devices by passing control signals over these.

A manual over-ride would also be available to permit operation in the event of a computer failure.

6.0 RESULTS AND CONCLUSIONS

The results of the study showed that there appears to have been little emphasis placed in the past in optimizing the electrical system in rail passenger vehicles. This is unfortunate considering the cost that can be incurred if extra engines are required to generate enough electricity to overcome the inefficiencies and to meet the peak electrical requirements.

The long life expectancy of the rail passenger vehicle makes it a good candidate for optimizing the electrical system as the increased capital costs have a better chance of being recovered many times during the life of the vehicle.

There is little incentive for the rail vehicle manufacturers to improve the efficiency of the electrical system as it would probably only add extra cost to the selling price of the vehicle as far as they are concerned. It will be up to the buyer to analyze his requirements and operating mode to determine the costs vs benefits of the many areas where the electrical system efficiency could be improved. The user would then have to work with the vehicle supplier to implement the electrical systems that would best serve his needs.

The main users of electricity in the several rail vehicles that were reviewed were the heating and air conditioning systems and these two areas offer the best opportunity for significant energy savings.

Micro-processor based controls would appear to offer many advantages to the passenger rail system including better control of the electrical systems with improved efficiency. They also can provide many enhanced control and safety systems relatively inexpensively as has been demonstrated in their use in the automotive industry.

Recommendations for future work include the following:

1. An analysis of present train systems such as the LRC to determine the extra costs being incurred by the inefficiency of the electrical system. From this it would be relatively easy to determine which "efficiency improving" suggestions are cost effective.

2. Future new passenger train purchases should be preceded with an extensive cost/benefit analysis of possible improvements to electrical systems.

3. The costs and advantages of micro-processor control systems for future train systems should be reviewed with regards to improved electrical efficiency and also improved service and safety of the train system.

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